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Relationships of rat damage to physical and yield characteristics of Hawaiian sugar cane

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Abstract

Two long-term data sets containing information on rat damage levels and measurements on physical and yield characteristics on a number of varieties of sugar cane were examined to ascertain if a relationship could be detected between rat damage and the other variables. One data set was collected over 6 years from experimental field plots on 5 plantations. The other data set was collected operationally over 9 years from a single plantation. Most correlations were not large and varied in sign among varieties, but some patterns of relationships with rat damage levels were indicated. The experimental field plot data provided indications that rat damage may be negatively related to elevation and the amount of sucrose in the sugar cane juices (percent pol) and positively related to the density of sugar cane stalks. The data from the single plantation indicated correlations of rat damage with the percentage of sour stalks in the field and with elevation. Our general conclusions are that overall sugarcane yields and quality are probably more influenced by cultural practices and environmental conditions than rat damage as a determining factor. Published by Elsevier Science Ltd.

1. Introduction

Sugarcane crops worldwide are susceptible to damage by rats. Mature sugar cane provides many of the essentials for rodent survival such as cover, readily available food, protection from avian predators, and an extension of favored habitat that a large monoculture provides (Taylor, 1972; Hampson, 1982). Substantial rat populations may build up in the long intervals between harvests (up to 36 months in Hawaii). Damage is inflicted to the cane when rodents gnaw through the rind, thus opening the cane to the secondary infections by bacteria and fungi that can severely reduce the cane quality and sugar content (Pemberton, 1925; Doty, 1945; Hood et al., 1971; Taylor, 1972; Jackson, 1977; Hampson, 1982).

In Hawaii, Polynesian rats (*Rattus exulans*), roof rats (*R. rattus*) and Norway rats (*R. norvegicus*) inhabit Hawaiian sugarcane fields and surrounding noncrop areas (Tobin and Sugihara, 1992) and cause extensive damage to growing sugarcane stalks (Pemberton, 1925; Doty, 1945; Fellows and Sugihara, 1977). The vulnerability of Hawaiian sugar cane to rat damage is increased because Hawaii is one of the few areas in the world where sugarcane is grown as a 2-year crop, which allows the sugar cane to lodge and form a thick mat. This provides cover for rodent populations and at the same time adds exposure time for rat damage to occur. In addition, many of the sugarcane growing areas in Hawaii have the fields situated between inaccessibly steep, heavily vegetated gullies that provide ready refuge areas from which rats can re-invade the fields. The relationships of rat damage levels with various physical characteristics of sugar cane, sugar yield, cultural and environmental situations are not well understood. Although not specifically designed to examine rat damage relationships, two sources of long-term data provided an unique opportunity to explore for relationships between damage and these characteristics. One data set emanated from horticultural field trials on sugar cane varieties and the other was a compilation of operational plantation records.

2. Methods

2.1. Study 1

Data for this study were collected over the course of 6 years using 245 Hawaiian Sugar Planters Association (HSPA)experimental field plots for testing standard and alternate varieties of sugarcane. The plots (12 × 12 m or

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9 × 9 m) were set up by HSPA personnel within commercial cane fields (Hawaiian Sugar Planters Association, 1970) located on the Davies Hamakua, Lihue, Mauna Kea, McBryde and Puna sugarcane plantations. Density of rat damaged sugarcane internodes was estimated using an extension of the Kendall–Moran method described by Engeman et al., 1994 (estimator KM2P) that requires measuring the distances (1) from randomly placed stakes to the closest damaged internode, (2) from those damage points to their nearest neighboring damaged internodes, and (3) from those neighboring damage points to their nearest neighboring damaged internodes. In addition, all stalks were counted within a 20 cm radius circle centered at each of the random sampling points used for the damage measurements. These counts were averaged to produce an estimate of average stalk density for each field test plot. At harvest of each test plot, 20 stalks were randomly selected to measure diameter (mm) and rind hardness (measured on a 100 point scale by a type D durometer). After harvest of each plot, the sugarcane plantations provided standard measurements of sugarcane characteristics for the varieties contained in each test plot. These variables included percent brix (hydrometer reading that estimates soluble solids in the juices), percent pol (polariscopic reading of the amount of sucrose in the juice), juice purity (calculated as the amount of pol in the juice multiplied by 100 and divided by the total solids in the juice), tons of cane per acre (TCA), and estimated tons of sugar per acre (ETSA). The distance (m) from each test plot to the nearest non-crop area and the elevation of the test plots were also recorded. Correlation analyses were applied to the 6 predominant sugarcane varieties planted (54–0775, 59–3775, 61–1721, 62–4671, 68–1158, 70–0144) to examine whether a relationship was indicated between density of rat damaged internodes and each of the other variables. Table 1 illustrates the number of test plots used for each of the 6 predominant varieties in each year. Measurements were also made on field test plots containing 6 other varieties (56–4848, 57–5174, 60–5657, 62–1526, 65–7052, 68–2235), but numbers of plots were insufficient for each variety ($n \leq 8$) for the correlation analyses to be considered reliable for producing general interpretations. In addition, Multiple regression analyses were calculated to explore what variable combinations might relate to damage for each variety. Optimal model selection was made for each variety by applying Akaike's information criterion (Akaike, 1969) to a backward selection process (e.g., Graybill, 1976).

2.2. *Study 2*

Personnel from Mauna Kea Agribusiness, Inc. collected pre-harvest sugarcane condition data over 9 years from 863 commercial plantings on the 6070 ha plantation. Estimates were made on the percent of stalks that were sour or dead in each field. Rat damage density was also estimated using the extension of the Kendall–Moran procedure described earlier. Percent brix, percent pol, TCA, and ETSA for each field were estimated at the time of milling. Field elevation was also reported. Here too, correlation analyses were applied to the 4 primary sugarcane varieties (59–3775, 68–1158, 70–0144, 74–1715) planted during this period to explore whether relationships were indicated in these data between density of rat damaged internodes and the other variables. Table 2 shows the number of fields harvested for the above 4 varieties for which measurements were made each year. Although data were recorded from fields containing 2 additional varieties (70–6957, 78–0292), sample sizes of fields were insufficient ($n \leqslant 5$) to apply interpretations to the results from correlation analyses.

3. Results

3.1. *Study 1*

We consider the correlation results summarized in Table 3 in an attempt to identify patterns among the varieties that relate rat damage density to the sugarcane variables. Descriptive statistics also are given for each variable on each variety. Correlations with rat damage were generally small and the signs on the correlations inconsistent across varieties. We took the more qualitative approach of examining for patterns in correlation results across the varieties. Elevation had very small nega-

Table 1
Number of field test plots sampled for each variety each over a 6 year period.

	Year						
Variety	1977	1978	1979	1980	1981	1982	Total
54-0775	6		8	18	16	2	50
59-3775	27	94	82	76	117	7	403
61-1721			7	11	20		38
62-4671			7	20	16		43
68-1158				17	55	1	73
70-0144			3	7	34	10	54

Table 2
Number of fields of each variety sampled each year by Mauna Kea Agribusiness, Inc. over a 9 year period.

Variety	1983	1984	1985	1986	1987	1988	1989	1990	1991	Total
					Year					
59-3775	33	65	17							115
68-1158					5	9	10			24
70-0144	9	74	99	114	114	48	16			474
74-1715			2	2	5	40	73	65	55	242

tive correlations with damage for 2 varieties, and 3 of the other 4 correlations were also negative. Similar results occurred for percent pol where correlations with damage were negative for 5 of 6 varieties, albeit 3 correlations were of very small magnitudes. Probably the strongest pattern was indicated for stalk density where the magnitudes of the correlations with damage tended to be larger than for the other variables and 5 of 6 were positive. Correlations with damage for most variables resulted in 4 of the 6 varieties having correlations with the same sign, but interpretations are at best speculative, especially with small correlations.

Although we did not consider sample sizes from the 6 additional sugarcane varieties measured to be reliable for useful interpretations, similar results were found for percent pol, as negative correlations with density of rat

Table 3
Correlation coefficients[fna)] of rat damage density with variables measuring sugarcane characteristics, and descriptive statistics, collected from varietal field test plots over a 6 year period.

Variety	Dam (m^2)	Elev (m)	Dist (m)	Hard (100 pt)	Diam (cm)	Variables[b] Dens (m^2)	Brix (%)	Pur (%)	Pol (%)	TCA (tons)	ETSA (tons)
54-0775 (n = 50 plots):											
r	1.00	−0.19	−0.08	−0.21	0.27	0.60	−0.09	0.04	−0.08	0.04	0.01
mean	6.71	413	197	31.1	2.61	13.2	16.6	87.6	14.6	123	13.5
s.e.	0.80	36	53	0.3	0.03	0.5	0.2	0.6	0.2	4	0.0
59-3775 (n = 403 plots):											
r	1.00	−0.11	0.04	−0.08	−0.20	0.35	−0.34	−0.06	−0.31	0.19	−0.02
mean	9.93	250	159	28.1	2.45	12.7	17.1	88.9	15.3	135	17.6
s.e.	0.42	8	9	0.7	0.06	0.2	0.1	0.4	0.1	2	0.2
61-1721 (n = 38 plots):											
r	1.00	0.26	−0.33	0.12	0.14	0.15	0.03	0.06	−0.02	−0.21	−0.32
mean	6.15	122	269	28.9	2.46	13.0	16.4	84.1	14.2	110	13.7
s.e.	0.80	9	66	1.5	0.13	0.5	0.5	2.4	0.5	5	1.0
62-4671 (n = 43 plots):											
r	1.00	−0.01	−0.33	0.21	0.26	−0.22	0.23	−0.17	0.14	−0.35	−0.31
mean	4.11	107	309	29.4	2.77	9.8	17.7	86.3	15.3	119	14.7
s.e.	0.74	9	60	1.3	0.12	0.3	0.2	0 .4	0.3	3	0.4
68-1158 (n = 73 plots):											
r	1.00	−0.45	−0.18	−0.08	−0.61	0.42	−0.17	−0.02	−0.33	0.22	−0.06
mean	2.96	281	99	30.4	2.78	12.4	15.8	86.1	14.1	134	15.5
s.e.	0.47	21	16	0.3	0.06	0.3	0.3	1.3	0.2	4	0.4
70-0144 (n = 54 plots):											
r	1.00	−0.08	0.01	−0.16	0.09	0.05	−0.00	0.07	−0.02	0.11	0.01
mean	4.23	285	127	29.0	2.92	11.4	16.4	80.9	14.6	112	15.3
s.e.	0.53	21	21	0.8	0.02	0.5	0.8	3.6	0.7	6	0.8

[a]Values of correlation coefficients that are listed as 0.00 or −0.00 are less than 0.01 with the indicated sign.
[b]Dam = density of damaged internodes; Elev = elevation of plot; Dist = distance from plot to nearest non-crop area; Hard = rind hardness on 100 point durometer scale; Diam = stalk diameter; Dens = stalk density; Brix = hydrometer estimate of soluble solids in the juices; Pur = juice purity as percent of pol in the juice; Pol = polariscopic reading of sucrose in the juice; TCA = tons of cane per acre; ETSA = estimated tons of sugar per acre.

damaged internodes were produced for 5 of these 6 lightly sampled varieties (distance to non-crop areas also produced negative correlations in 5 of these 6 varieties).

No discernable patterns from the multiple regression analyses emerged across varieties for the variable combinations that best related to damage. In addition, the R^2 values from the optimal model for each of the varieties only ranged from 0.21 to 0.59.

3.2. *Study 2*

Percent brix, percent pol, TCA, and ETSA showed no discernable pattern (correlations of negligible magnitude and/or no preponderance of positive or negative correlations) relating them to rat damage density (Table 4). Descriptive statistics for each variable are also given for each variety. The results for percent pol from Study 1 were not supported by these data, although this could be due to the data being collected on an operational basis with field as the measured unit, rather than sampling in a designed experiment with the smaller field test plots as the measured unit. The results for percent sour stalks seemed to be related to damage measurements as 3 of 4 correlations were positive and the single negative correlation coefficient was of negligible magnitude. The results for percent dead were not as strong as 3 of 4 correlations are inconsequential in magnitude. The correlations for elevation indicate the opposite pattern as for Study 1, with 3 of 4 varieties showing a positive relationship between elevation and damage and the fourth was negligible. Thus, the factors relating damage to elevation at work on the Mauna Kea Agribusiness plantation during these years do not appear to operate the same as for all plantations taken as a whole. The multiple regression results for Study 2 were weak, at best. The maximal R^2 among varieties for the best-fit model was 0.11. There also was no agreement among the varieties as to the variables included in the best-fit model.

4. Discussion

The extraction of relationships between rat damage density and sugarcane characteristics was hindered by the fact that we examined different varieties grown under a variety of circumstances. Within any given variety, the variables had only a limited breadth of measurements for producing a correlation with rat damage. For example, most varieties were planted in restricted elevation ranges. The varieties 54–0775 and 61–1721 were usually planted in upper elevations while 59 3775, 62 4671 and 70–0144 were usually planted in lower to middle elevation ranges (A. Ota, HSPA, personal communication) Therefore, relationships of rat damage to elevation may have been more difficult to discern because the variation in elevation within a variety that would be needed for explaining or predicting variation in damage levels was lacking. Such aspects were even further limited in Study 2 where the

Table 4
Correlations coefficients of rat damage density with variables measuring sugarcane characteristics with rat damage density, and descriptive statistics, from data collected by Mauna Kea Agribusiness, Inc. over a 9 year period.

Variety	Variables[a] Dam (m^2)	Elev (m)	Sour (%)	Dead (%)	Brix (%)	Pol (%)	TCA (tons)	ETSA (tons)
59-3775 (n = 115 fields):								
r	1.00	0.14	0.15	0.13	−0.14	−0.16	0.04	−0.08
mean	5.36	238	24.72	12.86	7.92	7.03	106.3	12.0
s.e.	0.29	11	0.03	0.01	0.11	0.10	1.8	0.2
68-1158 (n = 24 fields):								
r	1.00	0.25	0.32	−0.10	0.13	0.17	0.18	0.29
mean	11.30	344	3.88	2.72	6.64	5.86	95.8	10.0
s.e.	1.41	16	0.01	0.00	0.25	0.22	4.2	0.5
70-0144 (n = 474 fields):								
r	1.00	0.12	−0.07	−0.02	−0.13	−0.14	−0.16	−0.29
mean	7.89	233	6.21	6.57	7.66	6.73	99.7	11.5
s.e.	0.23	5	0.00	0.00	0.10	0.09	0.8	0.1
74-1715 (n = 242 fields):								
r	1.00	−0.02	0.15	−0.02	0.23	0.23	−0.05	−0.02
mean	9.93	211	3.18	2.32	5.50	4.76	93.0	9.2
s.e.	0.32	7	0.01	0.01	0.20	0.17	1.2	0.3

[a] Dam = density of damaged internodes; Elev = elevation of plot; Sour = estimate of percent sour stalks; Dead = estimate of percent dead stalks; Brix = hydrometer estimate of soluble solids in the juices; Pol = polariscopic reading of sucrose in the juice; TCA = tons of cane per acre; ETSA = estimated tons of sugar per acre.

data represented the circumstances from only one (large) plantation.

Furthermore, our ability to detect relationships between rat damage and sugarcane characteristics may have been tempered by the existence of ongoing rat control programs on the plantations, although information exists to suggest that current rat control measures are not very effective (Sugihara et al., 1995). Under the presumption of an effective control program, rat damage would not be permitted to increase beyond low amounts, thus not allowing observations on the full range of damage relative to the variables describing sugar cane characteristics. Ongoing rat control programs may insure that rat damage does not become a determining factor in sugarcane yields.

Related to this, any effects on sugarcane yields from rat damage would be primarily through infection to damaged stalk. However, these effects may be attenuated by genetic resistance to disease for which many varieties have been bred. Additionally, little is known about compensatory mechanisms of sugarcane. Damage to one stalk of a plant may lead to increased growth of other stalks or production of new stalks, which again would dilute the observable effects to yield from rat damage.

Various studies have indicated substantial losses to rats in Hawaiian sugarcane (Pemberton, 1925; Doty, 1945; Hood et al., 1971; Lindsey et al., 1971; Tobin et al., 1990). That strong negative relationships between rat damage density and the quality and yield variables were not found in either of these long-term data sets could well be due to yield and quality being overwhelmingly influenced by cultural practices and environmental conditions (including weather). Even though absolute losses to rats may be substantial, comparatively, factors such as fertilization, water regimes, varietal resistance to insects and infections, plant compensation, planting and other cultural practices may be more influential in determining yields.

Thus, the difficulties are evident in attempting to detect direct relationships between damage and yield when the yield measurements represent the cumulative effects of growing practices and conditions, including damage, over the entire crop cycle. Even further removed then is the ability to produce detectable relationships between animal populations and yield. Damage effects on yield require comparative information on yield variables where damage levels are manipulated in the face of the other circumstances. Until such specific information is available, growers will have to base timing and extent of rat damage-control methods and strategies on current knowledge of general rat population tendencies in and around cane fields, and on damage assessments through the crop cycle.

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